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Siluro-Devonian graptolite stratigraphy of the Catalonian Coastal Ranges

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ABSTRACT

Two facies characterize the Silurian and lower Devonian of the Catalonian Coastal Ranges, namely euxinic and pelagic carbonate facies. The first, is represented by black shales in which the *atavus, acinaces, cyphus, triangulatus, convolutus, ?sedgwickii, ellesae* and *tumescens* zones have been recognized. The graptolite succesion is far from complete on present evidence, but this is probably due to unfavorable environmental (taphonomic) conditions. This facies is similar to that prevailing throughout the Iberian massif and most of western Europe.

The pelagic carbonate facies is peculiar to the Pridoli and lower Devonian and corresponds to the facies type prevailing in the Western Mediterranean Area. It is characterized by the nodular texture of limestones and marls, with all gradations between nodular limestones, marls and slates. Massive nodular limestone, occur in the lower part of the sequence (La Creu Formation) while the alternation of limestones, marls and slates charaterizes the upper part (Olorda Formation). Orthoconic cephalopds, crinoids, conodonts and tentaculites are the most common fossils present; graptolites occur in some shale horizons in the lower part of the Olorda Formation. These graptolites give strong indications of the *uniformis* and *hercynicus* zones (Lochkovian). The uppermost part of the sequence has not provided any graptolite fauna, but according their dacrioconarid fauna it corresponds probably to the Pragian.

Key Words: Silurian. Devonian. Graptolites.

RESUMEN

En la sucesión Silurico-Devónica de las Cadenas Costeras Catalanas se presentan dos facies diferentes: facies euxinica y facies carbonatada pelágica. La primera de ellas esta representada por pizarras negras, a veces con abundantes sulfuros, en las que se han reconocido las zonas de *atavus, acinaces, cyphus, triangulatus, convolutus, ?sedgwickii, ellesae,* y *tumescens*. Estas zonas no representan la sucesión completa, pero ello es debido probablemente a condiciones desfavorables del medio (tafonómicas). La facies euxínica caracteriza la mayor parte del Silúrico y es similar a la que predomina en todo el Macizo Ibérico y la mayor parte de la Europa Occidental.

La facies carbonatada pelágica predomina en el Pridoliense y el Devónico inferior y es el tipo de facies propia del Mediterráneo occidental. Se caracteriza por la naturaleza nodulosa de las calizas y margas, presentandose todas las gradaciones entre calizas nodulosas, margas con nódulos calizos, margas y pizarras. La parte inferior de la sucesión está formada por calizas nodulosas masivas (Formación La Creu) mientras que la parte superior consiste en una alternancia de calizas, margas y pizarras (Formación Olorda). Los cefalópodos ortocónicos, crinoideos, conodontos y tentaculites son los fósiles más comunes presentes; en algunos horizontes de pizarras en la parte baja de la Formación Olorda se han encontrado además graptolites que indican las zonas de *uniformis* y de *hercynicus* (Lochkoviense). La parte más alta de la serie no ha proporcionado graptolites, pero según las faunas de dacrioconáridos que contiene corresponde probablemente al Praguiense.

INTRODUCTION

The Catalonian Coastal Ranges are two minor mountain ranges of Palaeozoic and Mesozoic rocks between the Tertiary Ebro basin and the Mediterranean, (fig. 1). They trend parallel to the Mediterranean coast and are separated from each other by a Miocene graben with the same trend. Palaeozoic rocks (granitoids, sedimentary and metasedimentary rocks) crop out extensively from Barcelona northwards, while to the southwest Mesozoic rocks predominate. Sedimentary and metamorphic rocks, the latter generally of low grade, are found in isolated areas, separated by post-Palaeozoic cover sediments and/or by post-tectonic Hercynian granitoids. The age of the Palaeozoic sequence exposed, ranges from probably the early Cambian (Les Guilleries, Montseny) to the Namurian or perhaps even the early Wesphalian (El Priorat). Nevertheless, due to the scarcity of fossils, reliable datings are lacking in most of the succession.

The most fossiliferous beds are found in the Silurian and the Devonian. The first fossil remains were collected at the end of the last century by Almera (1891, 1898, 1902) and determined by Barrois (1893, 1898, 1901). From these discoveries, the presence of the Silurian (graptolites) and Devonian (tentaculites and trilobites) was established, and the first tentative stratigraphical succession was given. Later on little attention was paid to the Palaeozoic of the Catalonian Coastal Ranges so that, during this century, the only contribution to the Palaeozoic stratigraphy are some graptolite finds (Puschmann, 1968a, b; Greiling & Puschmann, 1965) and a list of Silurian conodonts given by Walliser (1964), from around Barcelona.

The purposes of this paper are to review the Silurian and Devonian stratigraphy and their graptolite faunas, on the basis of a detailed survey of the area around Barcelona, based upon collections of specimens in the classic and in new fossiliferous localities (labelled GT) (fig. 2). Also two localities at Les Guilleries (labelled GG) and one in the Serra de Miramar (GM-1) have been studied. The reader interested in a more general geological description is referred to the papers by Julivert & Martinez (1980) and Julivert & Duran (1983).

Three units can be distinguished in the Silurian-Devonian succession. These, from top to bottom, are as follows (fig. 3):

3.— A sequence of green and reddish marls and shales, with interlayered limestone beds some 5 to 20 cm thick (Devonian).

2.— A massive nodular limestone (Silurian, except perhaps the uppermost 10 meters).

1.— A sequence of shales, mainly black (white when weathered) graptolitic shales, with some quartzites, cherts and thin lenticular limestone beds (Silurian).

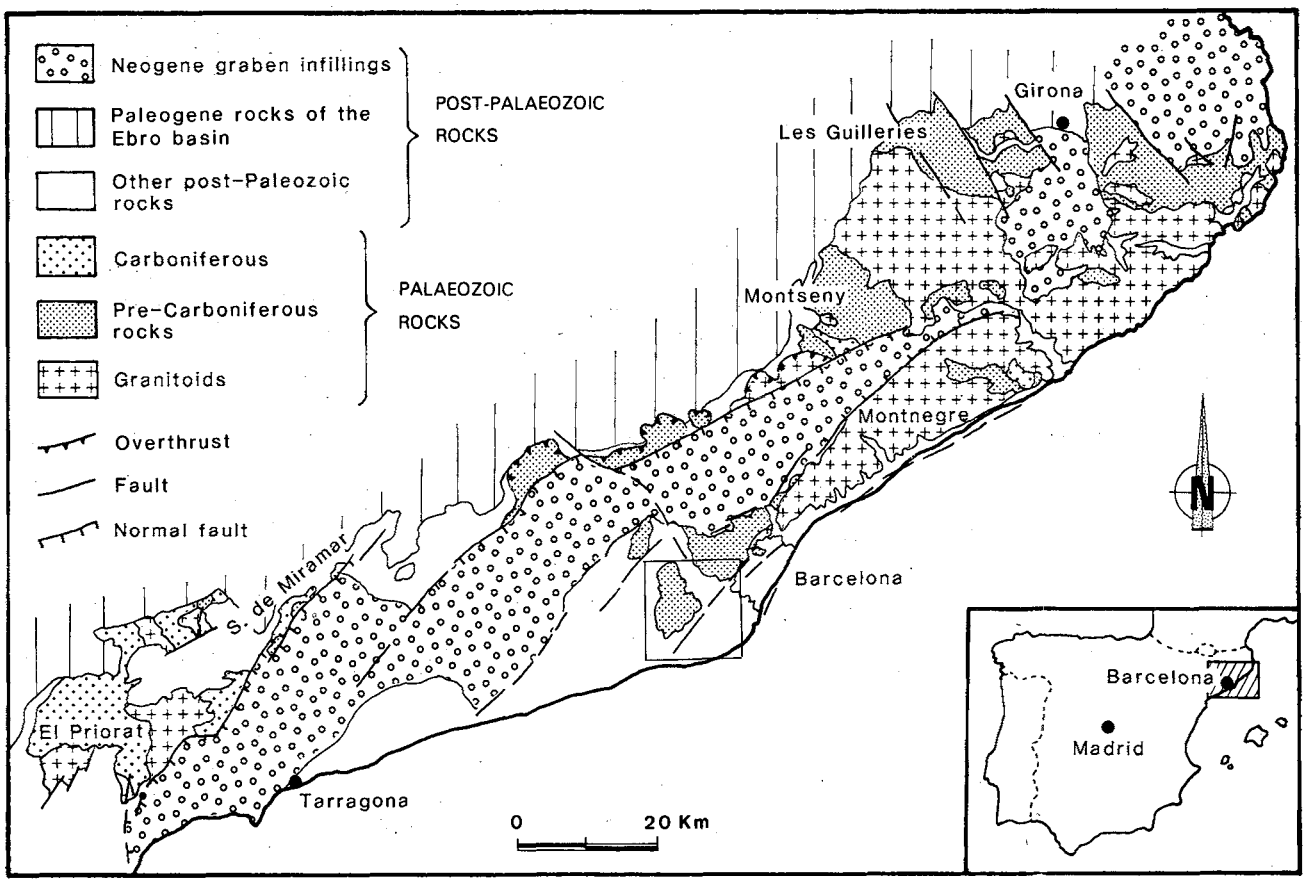

Figure 1.- Geological sketch of the Catalonian Coastal Ranges showing position of map represented in fig. 2.

Figura 1.- Esquema geológico de las Cadenas Costeras Catalanas indicando la posición del mapa de la fig. 2.

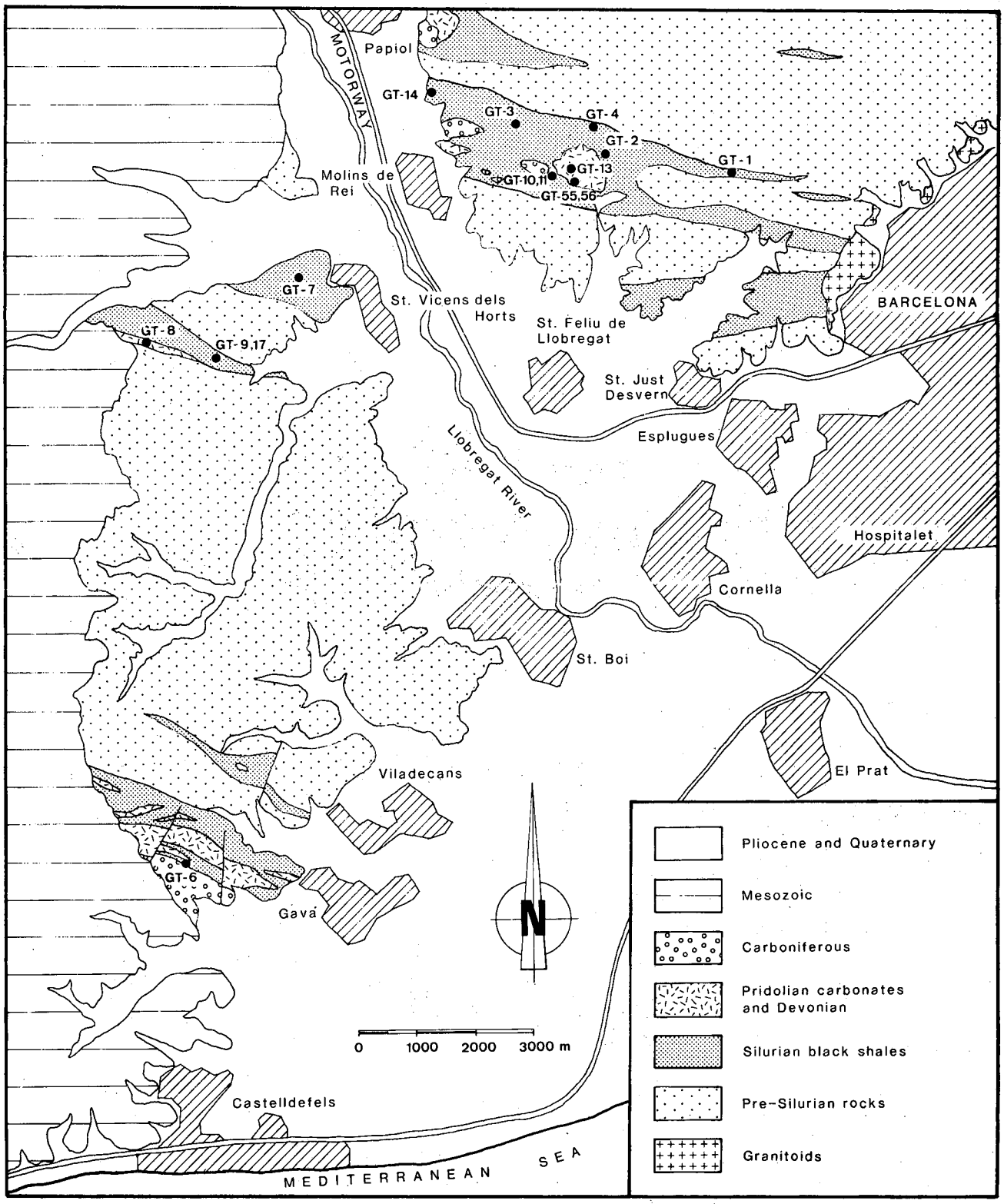

Figure 2.- Geological sketch of the sourroundings of Barcelona showing the fossiliferous localities.

Figura 2.- Esquema geológico de los alrededores de Barcelona con la situación de las localidades fosilíferas.

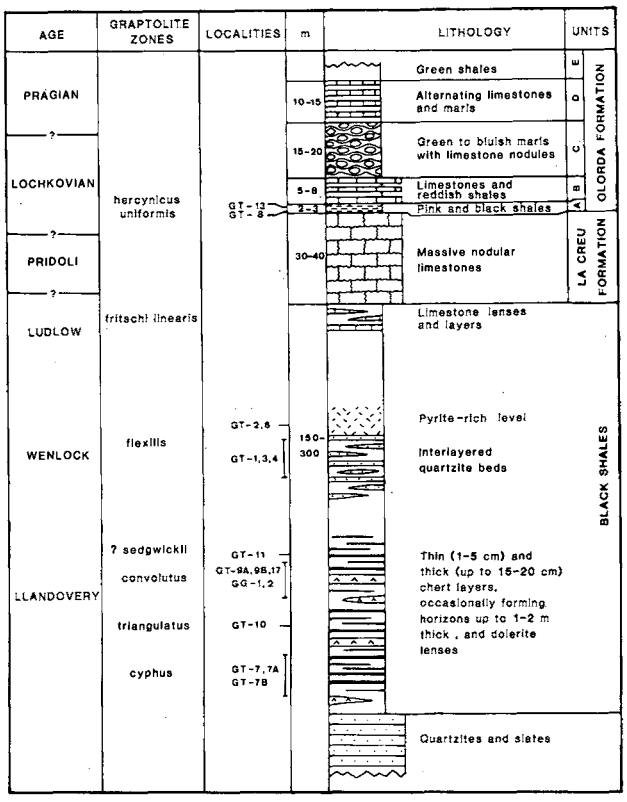

Figure 3.- Silurian-Devonian sequence.

Figura 3.- Columna estratigráfica del Sulúrico-Devónico.

THE SILURIAN BLACK SHALES

Lithology and thickness. Most of the Silurian comprises a shale formation and is similar to the Silurian of most of western Europe (Iberian and Armorican massifs, Pyrenees, Montagne Noire, Sardinia, etc.). The thickness can be tentatively evaluated at some 150-300 m, but it cannot be exactly determined because of tight folding. For the same reason there are no well exposed sections. Lithologically the unit consists predominantly of black shales, but there is sporadic occurrence of some other rock types and some differences in the characteristics of the shales which allow recognition of a lithostratigraphic succession.

In the area next to Barcelona, the Silurian black shales rest on a quartzite horizon, some 25-50 m thick, which might be correlated with the Bar Quartzite (Hartevelt, 1970) in the Eastern Pyrenees. This may represent either the top of the Ordovician or the lowermost part of the Silurian.

The lower part of the shale sequence is characterized by the presence of chert layers. The common occurrence of chert seems to be the most important peculiarity of the lower part of the sequence. Chert layers are found in all the localities where a Llandovery fauna has been collected (Can Farres, S. Vicens dels Horts, etc.). Dolerite lenses (sills) are also frequent in the lower part of the sequence. At El Remei, Llandovery graptolites have been found in black shales with chert layers close to a dolerite body.

Towards the middle part of the sequence there is a level of black shales with interlayered thin (2-20 cm) quartzite beds. This level has provided Wenlock faunas in several localities (Sta. Creu d'Olorda, Coll de la Mata, Can Tintorer etc.).

Also towards the middle part of the sequence there is a very characteristic level of black shales containing sulphide layers and nodules, very frequent and characteristic, but not very important in volume. The field relationships with the Wenlock shales and quartzities are not quite clear, although both levels crop out always very close to each other. It seems, however, that the black shales with sulphide deposits overlie the black shales and quartzites.

Finally, the upper part of the sequence consists of black, gray and green shales, with some limestone lenses towards the top, and has not provided any fauna. The contact with the overlying carbonate unit seems to be somewhat transitional, but it is nowhere clearly seen because, due to the ductility contrast between both units, it is always tectonized.

Age. In the Palaeozoic area near Barcelona graptolites have been collected from 17 localities in the Silurian black shales. In addition two localities in Les Guilleries have also provided graptolite faunas. From these findings, the *atavus, acinaces, cyphus, triangulatus, convolutus, ? sedgwickii, ellesae,* and *tumescens* zones have been recognized (table 1).

The lack of faunas corresponding to many graptolite zones is probably due to unfavourable environmental (taphonomic) conditions and in general the graptolites are concentrated in very thin horizons. The difficulty is in determining the age spread of the unit, that is to date its lowest and uppermost beds. The lowest zone recognized is the *atavus* zone, but it cannot be said how far this fauna is from the base of the unit. It cannot, therefore, be stated that the Llandovery is complete, and that the Silurian follows in continuity with the Ordovician, or if there is a hiatus.

Such a hiatus is commonly well seen in the Iberian massif (Truyols & Julivert, 1983), for over a large part of the massif the Silurian rests transgressively on different Ordovician units. At these localities the Silurian starts in general with the *convolutus* or the *gregarius* zones. Nevertheless, in some areas the Silurian rests on Ashgill rocks (Iberian Chain, and eastern Sierra Morena, in the Iberian massif), and consequently the sequence seems to be complete. Hafenrichter (1980), from detailed palaeontological surveying of the transitional beds, concluded that even in these sequences there is a small hiatus comprising the Hirnantian. The area where the lowest Silurian graptolites have been found is the Ossa-Morena zone, in the southern part of the Iberian massif. In this area the *acuminatus* zone has been recorded (Jaeger & Robardet, 1979), and a sedimentary continuity may exist from Ordovician to Silurian.

In the Catalonian Coastal Ranges, Caradoc and Ashgill rocks are found, but there is no biostratigraphical information on the transitional beds, so that the question of the existence or not of a stratigraphic continuity from Ordovician to Silurian cannot be yet resolved.

The age of the top of the shales has to be established mainly from the conodont faunas yielded by the overlying nodular limestones. Faunas indicating the *flexilis* zone are quite abundant, but they are placed some distance below the top of the sequence. One locality has given a Ludlow age (approximately *tumescens* Zone), but its position with respect to the top of the sequence can not be determinated. Greiling & Puschmann (1965) reported from a sequence of alternating shales and limestones in the Turo de Montcada a fauna containing *Monograptus fritschi linearis* Bouček. This sequence is placed below the massive nodular limestone and represents probably the transition between the graptolitic black shales and the overlying limestones. According to this fauna the top of the shale formation has to be placed at about the Ludlow-Pridoli boundary.

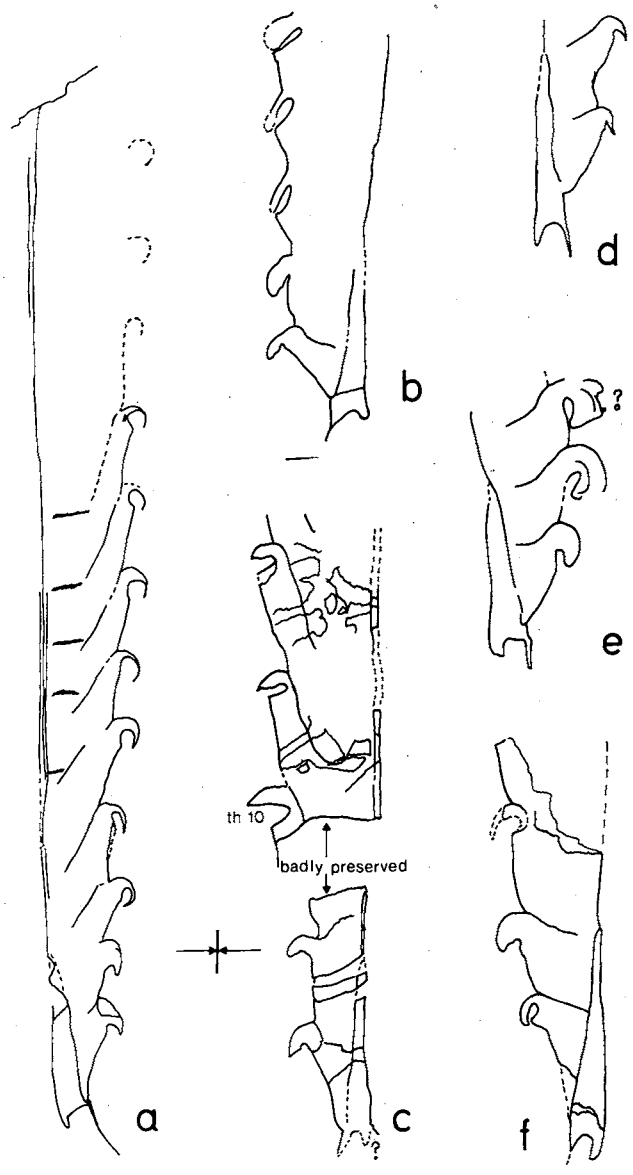

Figure 4.- a) *Monograptus uniformis uniformis* Pribyl, locality GM-1, specimen flattened; b-f, *Monograptus uniformis angustidens* Pribyl, locality GT-8, specimens in three dimensions, but figure c is of a specimen deformed as indicated by the arrows. The same specimen is also badly preserved betwen th 2 and th 10. All figures x 10.

Figura 4.- a) *Monograptus uniformis uniformis* Pribyl, localidad GM-1, ejemplar aplanado; b-f, *M. uniformis augustidens* Pribyl, localidad GT-8, ejemplares en tres dimensiones, pero la fig. f corresponde a un ejemplar deformado, en la forma indicada por las flechas. Este ejemplar se encuentra mal conservado entre las th 2 y 10. Todos los ejemplares x 10.

THE MASSIVE NODULAR LIMESTONES

Lithology and thickness. The massive nodular limestones and overlying Devonian limestones and shales occur in several small outcrops scattered throughout the Catalonian Coastal Ranges. The most important outcrops in the region of Barcelona are found in Sta. Creu d'Olorda, el Turó de Montcada, Gracia, Papiol, Molins de Rei and Gava. In the hills of Santa Creu d'Olorda and El Turo de Montcada the

GRAPTOLITE ZONES	*Saetograptus incipiens* (Wood)	*Saetograptus chimaera* (Barrande)	*Raphidograptus toerquisti* (Elles & Wood)	*Raphidograptus extenuatus* (Elles & Wood)	*R. longispinus* (Perner)	*Rastrites* cf. *hibridus* Perner	*P. regularis* (Törnquist)	*P. dubius* s.l.	*? Pristiograptus dubius* (Suess)	*Pristiograptus dubius* (Suess)	*Orthograptus* sp.	*M. ? sedgwickii* (Portlock)	*?? M. sedgwickii* (Portlock)	*M. sp. ex gr. revolutus* Kurck	*M. ? revolutus* (Kurck)	*M. cf. revolutus* (Kurck)	*M. ? retroflexus* Tullberg	*M. ex gr. priodon* (Bronn)	*M. lobiferus* (M'Coy)	*M. ? limatulus* Tornquist	*M. flexilis* Elles	*M. ? flemingii* (Salter)	*M. delicatulus* Elles & Wood	*M. cyphus* cf. *praematurus* Toghill	*? M. convolutus* (Hisinger)	*M. cf. convolutus* (Hisinger)	*? Monograptus concinnus* Lapworth	*Monoclimacis flumendosae* (Gortani)	*Glyptograptus* cf. *serratus* (Elles & Wood)	*Glyptograptus* sp.	*Diplograptus modestus* (Lapwe)	*Dimorphograptus* cf. *epilongissimus* Rickards	*C. ? ellesae* Gortani	*Cyrtograptus* ex gr. *rigidus* Tullberg	*Climacograptus* sp.	*C. sp. ex gr. rectangularis* (M'Coy)	*Climacograptus rectangularis* (M'Coy)	*?Bohemograptus bohemicus ? tenuis* (Bouček)	*Atavograptus atavus* (Jones)	SPECIES	LOCALITIES	LITHOLOGY
- *flexilis*									X												X																				GT-1	Coll de la Mata	Black shales and some thin quartzite layes
- *flexilis*									X												X																				GT-2	Ermita de Sta. Creu d'Olorda	Black shales
- *flexilis*																					X																				GT-3	Can Tintorer	Black shales and some thin quartzite layers
- *flexilis*																					X							X														GT-4	Vila Narcisa, near Sta. Creu d'Olorda	Black shales
- *flexilis* (approx.)										X							X											X														GT-6	Road Gavà - Begas Km	Black shales
- *cyphus*														X																							X						GT-7	St. Vicens dels Horts	Black shales and chert layers up to 20 cm thick
- *cyphus* (approx.)			X													X																						X		X		GT-7A	"	"
- *acinaces* (approx.)			X																														X	X								GT-7B	"	"
- *tumescens* (approx.)	X	X							X																															X			GT-7C	"	Black shales
? *convolutus*													X												X				X														GT-9A	El Remei	Black shales, chert layes up to 20 cm thick and dolerite lenses
- *convolutus*							X												X								X																GT-9B	"	"
- *triangulatus*					X										X																							X					GT-10	Can Farrés	Black shales and some thin (2-5 cm) chert layers
- *sedgwickii* ?												X																															GT-11	"	"
- *atavus*				X																					X																X		GT-14	Can Rabella	Black shales
? *convolutus*																			X							X																	GT-17	El Remei	Black shales and chert layers up to 20 cm thick
? *ellesae*								X														X													X	X							GT-55	Old quarry of Sta. Creu d'Olorda	Dark shales
? early Wenlock								X										X																									GT-56	Old quarry of Sta. Creu d'Olorda	Dark shales
- *convolutus*						X				X									X					X			X																GG-1	Road Girona - Les Planes Km 16	Black shales
- *convolutus*																			X	X				X			X				X												GG-2	Puig de la Banya de Boc	Black shales

limestones have been actively quarried, but the best section of the massive nodular limestones and overlying Devonian beds is still found at the first locality.

The unit is formed of gray-brown, quite homogeneous, and thick-bedded nodular limestones, containing crinoids and «*Orthoceras*». The thickness of the unit in Santa Creu d'Olorda is some 30-40 m.

Age. The unit has yielded an abundant conodont fauna (Walliser, 1964) indicating a Pridoli age. *Cardiola interrupta* Sow., reported in the last century by Barrois (1893) and Almera (1898) came also from this unit. The lowest horizon sampled by Walliser has provided, among others, *Spathognathodus inclinatus inflatus* Wal. and *Polygnathoides siluricus,* Br. & Mehl,. which indicate the lower part of the Pridoli. The highest levels contain faunas of the *eosteinhornensis* zone. *Scyphocrinites* s.p. occurs some 10 m below the tope of the unit.

The last meters of the unit might be Devonian, since the first meters of the following unit have yielded graptolites of the *hercynicus* Zone, but a clear Devonian fauna has not yet been found in the massive nodular limestones.

THE ALTERNATING LIMESTONES, MARLS AND SHALES

Lithology and thickness. The uppermost pre-Carboniferous unit in the Catalonian Coastal Ranges is an alternating sequence of limestones, marls and shales, only partially preserved due to pre-Carboniferous and pre-Triassic erosion. This unit is best exposed in the quarries of Santa Creu d'Olorda. At this locality it consists of five members, which from top to bottom are as follows (fig. 3):

5— Green shales 5-8 m.

4— Alternating shales and limestones 10-15 m.

3— Green to bluish marls with abundant limestone nodules 15-20 m.

2— Limestones in beds 10-20 cm thick, alternating with reddish shales 5-8 m.

1— Pink and black shales with nodules of metalic oxides and a limonitic horizon at the base 2-3 m.

At other localities, as for example in Papiol and south of the Llobregat river, these five members cannot be so clearly distinguished. South of the Llobregat river the upper part of the sequence consists of green shales with some thin carbonate horizons and thin interlayered silts and fine-grained sandstones with cross-lamination. This material seems to correspond to member 4, better preserved and thicker than in the locality of Santa Creu d'Olorda.

Age. Devonian graptolites have been found in Santa Creu d'Olorda in members 1 and 2. Graptolites in member 1 are quite abundant and have been collected within the quarried area. These graptolites indicate the *hercynicus* Zone (Lochkovian). On the other side of the Llobregat river, in locality GT-8 (Can Castany), a graptolite fauna indicating the *uniformis* Zone has been found. Although the stratigraphical position of this fauna cannot be precisely stated from field evidence, according to its age and to the lithology (black and pink shales) it has to be placed in the lower part of member 1. This fauna might indicate that the Pridoli — Devonian boundary should be placed near the top of the massive nodular limestone. A similar fauna with *M. uniformis uniformis* has also been found in the Serra de Miramar (locality GM-1).

Member 2 has provided one specimen, found 1.5 m above its base, and several more in broken blocks of which the precise position within the member is not known. Members 2,3 and 4 have provided also quite abundant tentaculites although in general poorly preserved, indicating an early Devonian age. Higher in the sequence no more graptolites have been found. The rest of the fauna has to be studied, but it seems likely that the sequence preserved reached at the most the Pragian.

CONCLUDING REMARKS

Two facies characterize the Silurian and lower Devonian of the Catalonian Coastal Ranges, namely euxinic and pelagic carbonate facies. The euxinic facies is represented by black shales forming essentially the Llandovery, Wenlock and Ludlow, and containing graptolites as almost the only fauna present. This facies is similar to that prevailing throughout the Iberian massif and most of western Europe.

TABLE 1.- Silurian graptolites in the Catalonian Coastal Ranges. Location of localities near Barcelona, labeled GT, is found in fig. 2. Localities labeled GG, are found in Les Guilleries; GG-1 in the Girona-Les Planes road, Km 16, and GG-2 in the southern slope of the Puig de la Banya de Boc, 500 m from locality GG-1.

TABLA 1.- Graptolites silúricos de las Cadenas Costeras Catalanas. La situación de las localidades próximas a Barcelona, rotuladas GT, puede verse en la figura 2. Las localidades rotuladas GG corresponden a Les Guilleries; GG-1 se encuentra en la carretera Gerona-Les Planes, Km 16, y GG-2 en la vertiente Sur del Puig de la Banya de Boc, a 500 m de la localidad GG-1.

The pelagic carbonate facies is peculiar to the Pridoli and lower Devonian. It is characterized by the nodular texture of the limestones which can be either massive, thick bedded (Pridoli), or alternating with marls and shales (Devonian). In the Devonian, all gradations exist between nodular limestones, marls with limestone nodules, marls, and shales. The most common fossils present are conodonts, trentaculites, orthoconic cephalopods and crinoids, together with graptolites in the shale horizons. Scarcity of shelly fauna (brachiopods) and presence of pelagic and hemipelagic species together with a small thickness (less than 100 m from the base of the Pridoli to the top of the lower Devonian) indicate a pelagic, starved environment.

The existence of the above facies in the upper Silurian and/or the lower Devonian is peculiar to the western Mediterranean area (Eastern Pyrenees, Calatonian Coastal Ranges, Sardinia), in contrast to most of the Iberian massif, where, except in the Ossa-Morena zone (southern part of the massif) terrestrial shallow water formations prevail around the Silurian-Devonian bounday.

GRAPTOLITE BIOSTRATIGRAPHY

On the whole the faunas established are well founded but the graptolite succession in the Silurian is far from complete on present evidence (Table 1): thus the lower and middle Llandovery is proven on the grounds of six assemblages in total, but above the Llandovery only part of the Wenlock is certain, and part of the Ludlow.

The Locality GT-7 referred to the *cyhus* Zone is the least certain, but the occurrence of *Rhapidograptus toernquisti* (Elles and Wood) with species belonging to the groups of *Monograptus revolutus* Kurck and *Climacograptus rectangularis* (McCoy) suggests a pre-*triangulatus* level and post-*acinaces* level. GT-10 is clearer in that *Rastrites longispinus* (Perner) is present yet the characteristically earlier forms of *C. rectangularis* and *M. revolutus* persist, proving post-*cyphus* Zone strata, yet probably a pre-*magnus* Zone level.

Locality GT-14 is certainly referable to the *atavus* Zone with the occurrence of several specimens of *Coronograptus cyphus* cf. *praematurus* (Toghill) and *Rhaphidograptus extenuatus* (Elles & Wood); whilst the *acinaces* Zone is suggested at locality GT-7B on the occurrence of *Diplograptus modestus* Lapworth and *Dimorphograptus* cf. *epilongissimus* Rickards.

Localities GG-1 and 2 both yield an unambiguously *convolutus* Zone fauna with the relatively rare species

TABLE 2.- Devonian graptolites in the Catalonian Coastal Ranges. Location of localities near Barcelona, labeled GT, is indicated in fig. 2. Locality GM-1 is situated in the Serra de Miramar, near Figuerola.

TABLA 2.- Graptolites devónicos de las Cadenas Costeras Catalanas. La situación de las localidades próximas a Barcelona, rotuladas GT, se indica en la figura 2. La localidad GM-1 se encuentra en la Sierra de Miramar, junto a Figuerola.

GRAPTOLITE ZONES	*Monograptus uniformis angustidens* Přibyl	*Monograptus uniformis uniformis* Přibyl	*Linograptus posthumus* (Richter)	cf. *Monograptus hercynicus* Perner	LOCALITIES
- *hercinicus*			X	X	GT-13 Quarry of Sta. Creu d'Olorda
- *uniformis*	X				GT-8 Cervelló (Can Castany)
- *uniformis*		X			GM-1 Serra de Miramar

M. convolutus almost certainly present at both localities (only preservational problems raising a shadow of doubt) and an association of other typically *convolutus* Zone forms (Table 1). The remaining M. Llandovery locality of GT-11 has what seem to be badly preserved specimens of *Monograptus sedgwickii* (Portlock). This species first appears in the *convolutus* Zone, near the top, achieving an acme in the *sedgwickii* Zone. The presence of the eponymous species is not enough to establish the zone.

The remaining Silurian localities in the region are all referable to the middle Wenlock (upper part of the Sheinwoodian Stage) and four of the localities certainly to the *flexilis* Zone (= *linnarssoni* Zone).

M. flexilis sensu stricto is, as in other parts of the world, very common and quite well preserved, its characteristic curvature enabling easy identification even in tectonically deformed strata (see Palaentological Notes).

No other Wenlock or Praguian has yet been found on graptolite evidence but locality GT-7C is of approximately *tumescens* (Ludlow) Zone age. The succeeding Devonian (Table 2) is clearly demostrated with strong indications of the *uniformis* and *hercynicus* zones. As far as we are aware the species *M. uniformis* Pribyl and *Linograptus posthumus* (Richter) have not previously been recorded from the region, but Greiling and Puschmann (1965) record *M. hercynicus* Perner.

PALAEONTOLOGICAL NOTES

The Llandovery forms recorded differ little from previous descriptions of the species from Europe, but the preservation in places leaves much to be desired and is reflected to some degree in the number of question marks, ex gr. references, and *sensu lato* references in Table 1. No formal descriptions are thus attempted.

The Wenlock forms, particulary *M. flexilis* display a striking and interpretable tectonic deformation. When allowances are made for the deformation the probable dimensions can be seen to differ little from those originally given by Elles (1900). On the other hand the deformation itself can be spectacular as in the case of one specimen which has a flattened dorso-ventral width of 4.4mm only 10mm from the proximal end. Similarly the characteristic S-shaped curvature varies from a gentle flowing curvature to a very strongly sigmoidal curvature.

Cleavages are variable. In GT-1 and 2 there are two bedding plane lineations intersecting at 60°; one cleavage plane being at 45° to the bedding, the other at a higher angle but less clear. GT-4 has a dominant crenulation cleavage parallel to the bedding; and GT-3 has one dominant cleavage at 20° to the bedding. In all four localities most graptolites are both diagenetically flattened and, obviously, tectonically deformed. Almost all dimensions are considerably increased; both thecae and rhabdosomes look «big», in most instances, to the naked eye.

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